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CLAIM OF PRIORITY

Honorable Assistant Commissioner for Patents and Trademarks,
Washington, D.C. 20231

Sir:

Applicants in the above-identified application, hereby claim the priority date under the International Convention of the following Swedish application:

Appln. No. 9903944-8 filed: October 29, 1999

as acknowledged in the Declaration of the subject application.

A certified copy of said application is being submitted herewith.

Respectfully submitted,

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ANTENNA DEVICE AND METHOD FOR TRANSMITTING AND RECEIVING RADIO WAVES

TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to the field of antennas and particularly to an antenna device for transmitting and receiving radio waves, to a radio communication device comprising said antenna device, and to a method for transmitting and receiving radio waves, respectively.

BACKGROUND OF THE INVENTION

In modern radio communication industry, there is an ever-increasing demand for smaller and more versatile portable terminals such as, e.g. hand-portables telephones. It is well known that the size of an antenna is critical for its performance, see Johnsson, Antenna Engineering Handbook, McGrawHill 1993, chapter 6. The interaction between antenna, telephone body and proximate environment, such as e.g. the user himself, will become more important than ever. Since recently, there is also normally a requirement that two or more frequency bands shall be supported. It is thus a formidable task to manufacture such compact and versatile terminals, which exhibit good antenna performance under a variety of conditions.

When manufacturing a hand-portable telephone today the antenna is commonly adapted to the characteristics of this specific telephone and to be suited for a default use in a default environment. This means that the antenna can not later on be adapted to any specific condition under which a certain telephone is to be used or to suit a different hand-portable telephone. Thus, each model of a hand-portable telephone must

be provided with a specifically designed antenna, which normally can not be optimally used in any other telephone model.

The radiating properties of an antenna device for a hand-held wireless communication device depends heavily on the shape and size of the support structure such as a printed circuit board (PCB) of the device and of the telephone casing. All radiation properties, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern are a product of the antenna device itself and its interaction with the PCB and the telephone casing. Thus, all references to radiation properties made below are intended to be for the whole device in which the antenna is incorporated.

What has been stated above is true also with respect to other radio communication devices, such as cordless telephones, telemetry systems, wireless data terminals, etc. Thus, the antenna device of the invention is applicable on a broad scale in various communication devices.

Receiving antennas, with diversity functionality, whereby adaptation to various radio wave environments is performed, are known through e.g. EP-A2-0,852,407, GB-A-2,332,124 and JP-A-10,145,130. Such diversity functionality systems may be used to suppress noise, and/or undesired signals such as delayed signals, which may cause inter-symbol interference, and co-channel interfering signals, and thus improve the signal quality, but requires a complex receiver circuitry structure, including multiple receiver chains, and a plurality of antenna input ports.

Switchable antennas are known in the literature e.g. for achieving diversity.

WO 99/44307 discloses a communication apparatus with antenna-gain diversity. The apparatus comprises a first and a second antenna element, of which both or only one can be coupled to an antenna-signal node. The antenna element not coupled to the node is electrically coupled to signal ground.

EP-A1-0,546,803 discloses a diversity antenna comprising a single antenna element. The antenna element is in the form of a quarter wave monopole, which can be fed alternately at one end or the other from a common RF feed source.

US-A1-5,541,614 discloses an antenna system including a set of center-fed and segmented dipole antennas embedded on top of a frequency selective photonic bandgap crystal. Certain characteristics of the antenna system can be varied by connecting/disconnecting segments of the dipole arms to make them longer or shorter, for instance.

However, none of these prior art arrangements describes any switchable antenna elements that are connected or disconnected on some intelligent basis, e.g. when needed due to signal conditions. Said EP-A1-0,546,803 mentions the possibility of intelligent switching as such, but there is no indication of <u>how</u> to control the switching.

SUMMARY OF THE INVENTION

It is a main object of the present invention to provide an antenna device for transmitting and receiving radio waves, connectable to a radio communication device, and comprising transmitter and receiver sections, said receiver section

including an antenna structure switchable between a plurality of antenna configuration states, each of which is distinguished by a set of radiation related parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern, and a switching device for selectively switching said antenna structure between said plurality of antenna configuration states, which antenna device is versatile and adaptable to various conditions and suitable for obtaining desired functions.

In this respect, it is a particular object of the invention to provide such an antenna device, which exhibits improved performance in comparison with antenna devices of prior art.

It is a further object of the invention to provide an antenna device, which can be adapted in order to suite different models of radio communication device, after it has been installed therein.

It is another object of the invention to provide an antenna device of which certain characteristics are controllable, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern, and diversity.

It is an additional object of the invention to provide an antenna device, which exhibits a controllable interaction between its antenna structure and switching device.

It is still a further object to provide an antenna device that is simple, lightweight, easy to manufacture and inexpensive.

It is yet a further object to provide an antenna device being efficient, easy to install and reliable, particularly mechanically durable, even after long use.

It is still a further object of the invention to provide an antenna device suited to be used as an integrated part of a radio communication device.

These objects among others are, according to the invention, attained by an antenna device, by a radio communication device, and by a method as claimed in the appended Claims.

In the claims the expression "antenna structure" is intended to include active elements connected to the transmission (feed) line(s) of the radio communication device circuitry, as well as elements that can be grounded or left disconnected, and hence operate as e.g. directors, reflectors, impedance matching elements, and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description of embodiments of the present invention given hereinbelow and the accompanying Figs. 1-7 which are given by way of illustration only, and thus are not limitative of the invention.

Fig. 1 displays schematically a block diagram of an antenna module for transmitting and receiving radio waves according to an embodiment of the present invention.

Fig. 2 displays schematically receiving or transmitting antenna elements and a switching device for selectively connecting and disconnecting the receiving antenna elements as part of an antenna module according to the present invention.

Fig. 3 displays schematically a receiving or transmitting antenna structure and a switching device for selectively grounding said receiving antenna structure at a variety of different points as part of an antenna device according to the present invention.

Fig. 4 is a flow diagram of an example of a switch-and-stay algorithm for controlling a switching device of an inventive antenna device.

Fig. 5 is a flow diagram of an alternative example of an algorithm for controlling a switching device of an inventive antenna device.

Fig. 6 is a flow diagram of a further alternative example of an algorithm for controlling a switching device of an inventive antenna device.

Fig. 7 displays schematically receiving or transmitting antenna elements and a switching device for selectively connecting and disconnecting the receiving antenna elements as part of an antenna module according to yet a further embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following description, for purposes of explanation and not limitation, specific details are set fourth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known devices and methods are

omitted so as not to obscure the description of the present invention with unnecessary details.

Inventive antenna module (Fig. 1)

With reference to Fig. 1 an antenna device or module 1 according to an embodiment of the present invention comprises separated transmitter (TX) 2 and receiver (RX) 3 RF sections.

Antenna module 1 is the high frequency (HF) part of a radio communication device (not shown) for transmitting and receiving radio waves. Thus, antenna module 1 is preferably arranged to be electrically connected, via radio communications circuitry, to a digital or analogue signal processor of the radio communication device.

Antenna module 1 is preferably arranged on a carrier (not shown), which may be a flexible substrate, a MID (molded interconnection device) or a PCB. Such an antenna module PCB may either be mounted, particularly releasably mounted, together with a PCB of the radio communication device side by side in substantially the same plane or it may be attached to a dielectric supporting means mounted e.g. on the radio device PCB such that it is substantially parallel with it, but elevated therefrom. The antenna module PCB can also be substantially perpendicular to the PCB of the radio communication device.

Transmitter section 2 includes an input 4 for receiving a digital signal from a digital transmitting source of the radio communication device. Input 4 is via a transmission line 5 connected to a digital to analogue (D/A) converter 6 for converting the digital signal to an analogue signal. Converter 6 is further, via transmission line 5, connected to an

upconverter 7 for upconverting the frequency of the analogue signal to the desired RF frequency. Upconverter 7 is in turn connected to a power amplifier (PA) 8 via transmission line 5 for amplification of the frequency converted signal. Power amplifier 8 is further connected to a transmitter antenna device 9 for transferring the amplified RF signal and for radiating RF waves in dependence on the signal. A filter (not shown) may be arranged in the signal path before or after the power amplifier.

A device 10 for measuring a reflection coefficient, e.g. voltage standing wave ratio (VSWR), in the transmitter section is connected in transmitter section 3, preferably as in Fig. 1 between power amplifier 8 and transmitter antenna device 9, or incorporated in transmitter antenna device 9.

Transmitter antenna device 9 comprises a switching device 11 connected to transmission line 5 and a transmitting antenna structure 12, which is switchable between a plurality of (at least two) antenna configuration states, each of which is distinguished by a set of radiation related parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern.

Receiver section 3 includes a receiving antenna structure 13 for receiving RF waves and for generating an RF signal in dependence thereof. Receiving antenna structure 13 is switchable between a plurality of (at least two) antenna configuration states, each of which is distinguished by a set of radiation related parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern. A switching device 14 is arranged in proximity thereof for selectively switching antenna

structure 13 between the antenna configuration states. The receiving antenna structure 13 and switching device 14 may be arranged integrally in a receiver antenna device 15.

Antenna structures 12 and 13 may comprise a plurality of elements connectable to transmission lines 5 and 16, respectively, or to ground (not shown) and/or comprise a plurality of spaced points of connection connectable to respective transmission lines 5 and 16 or to ground, respectively, which will be described further below.

Antenna structure 13 is further connected, via transmission line 16, to one or several low noise amplifiers (LNA's) 17 for amplifying the received signal. The RF feeding of antenna structure 13 can be achieved via switching device 14 as in the illustrated case, or can be achieved separately, outside of switching device 14.

If reception diversity is used the signal outputs from the low noise amplifiers 17 are combined in a combiner 18. The diversity combining can be of switching type, or be a weighted summation of the signals.

Transmission line 16 is further connected to a downconverter or downmixer 19 for downconverting the frequency of the signal and to an analogue to digital (A/D) converter 20 for converting the received signal to a digital signal. The digital signal is output at 21 to digital processing circuitry of the radio communication device.

According to the invention there is provided a control device 22 for receiving a first measured operation parameter indicative of the quality of transmission of radio frequency waves by antenna module 1, and a second measured operation

parameter indicative of the quality of reception of radio frequency waves by antenna module 1, and for controlling either switching device 11 or switching device 14, or both, and thus the selective connecting and disconnecting of parts of antenna structures 12 or/and 13, in dependence on the received first and second measured operation parameters in order to improve the quality of said transmission or/and said reception.

The first measured operation parameter is preferably a measure representing the reflection coefficient, e.g. voltage standing wave ratio (VSWR), as measured by device 10 at transmitter section 2. Alternatively, it may be a measure of the quality of a transmitted channel, which may be measured at a receiving base station and reported back to the radio communication device. The second parameter, which is indicative of the quality of reception of radio frequency waves, may be bit error rate (BER), carrier-to-noise (C/N) ratio or carrier-to-interference (C/I) ratio as measured by the radio communication device. Alternatively, the second parameter is a parameter measurable within antenna module 1, such as received signal strength indicators (RSSI)

By means of switching device 11 or/and 14 the connection and disconnection of parts of antenna structures 12 or/and 13 is easily controllable. By reconfiguring the antenna structures, which is connected to the respective transmission line, radiation related parameters such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern can be altered.

Preferably, at installation of antenna module 1 in a particular model of a radio communication device, control device 22 is arranged for controlling switching device 11 or/and 14 to

switch state in dependence on the received first and second measured operation parameters, so as to adapt said antenna module to suit said model.

The operation parameters values are preferably received by control device (22) repeatedly during use, by sampling at regular time intervals or continuously.

Furthermore, during use of antenna module 1 in a radio communication device, control device 22 is arranged for controlling switching device 11 or/and 14 to switch state in dependence on said repeatedly received first and second measured operation parameters, so as to dynamically adapt antenna module 1 to objects in the close-by environment of the radio communication device. Hence, the performance of antenna module 1 may be continuously optimized during use.

Control device 22 preferably comprises a central processing unit (CPU) 23 with a memory 24 connected to measuring device 10 via connections 25, 26, to switching device 11 via lines 26, 28, and to switching device 14 via line 27. CPU 23 is preferably provided with a suitable control algorithm and memory 24 is used for storing various antenna configuration data for the switching. Switching device 11 and 14 preferably comprise a microelectromechanical system (MEMS) switch device.

CPU 23 thus may receive measured VSWR values from VSWR measuring device 10 through lines 25, 26, measured BER, (C/N) or (C/I) ratios from the digital radio communication device via a control port 29 and a control line 29a, and processes each received parameter value.

If CPU 23 finds it suitable (according to any implemented control algorithm) it sends switching instruction signals to switching device 11 or/and 14.

Furthermore, control port 29 of antenna module 1 is used for signaling between CPU 23 and digital circuitry of the radio communication device via line 29a. Hereby, power amplifier 8, low noise amplifiers 17, and combiner 18 may be controlled via lines 30, 31, and 32, respectively. In Fig. 1, finally, reference numeral 33 indicates a parallel-serial converter arranged in transmitter section 2 for converting parallel signaling lines 25, 28, 30 to a serial line 26. This is for reducing the number of lines, and thus connections, between transmitter section 2 and receiver section 3.

Optionally, CPU 23, memory 24 and control port 29 may be located in the transmitter section 2 and hence parallel-serial converter 33 is arranged in receiver section 3 in order to attain the same object.

The antenna module 1 as illustrated in Fig. 1 has only digital ports (input 4, output 21, and control port 29) and thus, it may be referred to as a digital controlled antenna (DCA).

However, it shall be appreciated that an antenna module according to the present invention does not necessarily have to include A/D and D/A converters, frequency converters or amplifiers. In any of these cases the antenna module will obviously have analogue input and output ports.

Operation environments

Next, various operation environments that may effect the performance of the antenna device or module in accordance with the invention will be described.

The antenna parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern of a small-sized wireless communication device are affected by objects in the proximity of the device. By proximity is here meant the distance within which the effect on the antenna parameters is noticeable. This distance extends roughly about one wavelength from the device.

A small-sized wireless communication device, such as a mobile telephone, can be used in many different close-by environments. It can for example be held to the ear as a telephone, it can be put in a pocket, it can be attached to a belt at the waist, or it can be held in the hand. Further, it can be placed on a metal table. Many more operation environments may be enumerated. Common for all environments is that there may be objects in the proximity of the device, thereby affecting the antenna parameters of the device. Environments with different objects in the proximity of the device have different influence on the antenna parameters.

Two specific operation parameters will in the following be specifically discussed.

The free space (FS) operation environment is obtained by locating the radio communication device in empty space, i.e. with no objects in the proximity of the device. Air surrounding the device is here considered free space. Many operation

environments can be approximated by the free space environment. Generally, if the environment has little influence on the antenna parameters, it can be referred to as free space.

The talk position (TP) operation environment is defined as the position, in which the radio communication device is held to the ear by a user. The influence on the antenna parameters varies depending on the person that is holding the device and on exactly how the device is positioned. Here, the TP environment is considered as a general case, i.e. covering all individual variations mentioned above.

Resonance frequency (Fig. 2)

Next, various radiation related parameters that may be controlled in accordance with the invention, such as resonance frequency, input impedance and radiation pattern, will be described in more detail.

Antennas for wireless radio communication devices experience detuning due to the presence of the user. For many antenna types, the resonance frequency drops a few percent when the user is present, compared to when the device is positioned in free space. An adaptive tuning between free space (FS) and talk position (TP) can reduce this problem substantially.

A straightforward way to tune an antenna is to alter its electrical length, and thereby altering the resonance frequency. The longer the electrical length is, the lower is the resonance frequency. This is also the most straightforward way to create band switching, if the change in electrical length is large enough.

In Fig. 2 is shown a meander-like antenna structure 35 arranged together with a switching device 36 comprising a plurality of switches 37-49. Antenna structure 35 may be seen as a plurality of aligned and individually connectable antenna elements 50-54, which in a connected state are connected to a feed point 55 through switching device 36. Feed point 55 is further connected to a low noise amplifier of a receiver circuitry (not shown) of a radio communication device, and hence antenna structure 35 operates as a receiving antenna. The low noise amplifier may alternatively be located in an antenna module together with the antenna structure 35 and the switching device 36. Optionally, feed point 55 is connected to a power amplifier of a radio communication transmitter for receiving an RF signal, and hence antenna structure 35 operates as a transmitting antenna.

A typical example of operation is as follows. Assume that switches 37 and 46-49 are closed and remaining switches are opened and that such an antenna configuration state is adapted for optimal performance when being arranged in a hand-portable telephone located in free space. When the telephone is moved to talk position, the influence of the user lowers the resonance frequency and thus, in order to compensate for the presence of the user, switch 49 is opened, whereby the electrical length of the connected antenna structure is reduced and accordingly the resonance frequency is increased. This increase shall with an appropriate design of antenna structure 35 and switching device 36 compensate for the reduction as introduced when the telephone is moved from free space to talk position.

The same antenna structure 35 and switching device 36 may also be used for switching between two different frequency bands such as GSM900 and GSM1800.

For instance, if an antenna configuration state, which includes antenna elements 50-53 connected to feed point 55 (switches 37 and 46-48 closed and remaining switches opened), is adapted to suit the GSM900 frequency band, switching to the GSM1800 frequency band may be effectuated by simply open switch 47, whereby the electrical length of the presently connected antenna structure (elements 50 and 51) is reduced to approximately half the previous length, implying that the resonance frequency is approximately doubled, which would be suitable for the GSM1800 frequency band.

Impedance (Fig. 3)

Instead of tuning a detuned antenna, one can perform adaptive impedance matching, which involves letting the resonance frequency be slightly shifted and compensate this detuning by means of matching.

An antenna structure can have feed points at locations. Each location has a different ratio between the E and H fields, resulting in different input impedances. This phenomenon can be exploited by switching the feed point, provided that the feed point switching has little influence on the rest of the antenna structure. When the antenna experiences detuning due to the presence of the user (or other object), the antenna can be matched to the feed line impedance by altering for example the feed point of the antenna structure. In a similar manner, RF grounding points can be altered.

In Fig. 3 is schematically shown an example of such an implementation of an antenna structure 61 that can be selectively grounded at a number of different points spaced apart from each other. Antenna structure 61 is in the

illustrated case a planar inverted F antenna (PIFA) mounted on a PCB 62 of a radio communication device. Antenna 61 has a feed line 63 and N different spaced ground connections 64. By switching from one ground connection to another, the impedance is slightly altered.

Moreover, switching in/out parasitic antenna elements can produce an impedance matching, since the mutual coupling from the parasitic antenna element to the active antenna element produces a mutual impedance, which adds to the input impedance of the active antenna element.

Other typical usage positions than FS and TP can be defined, such as for instance waist position, pocket position, and on a steel table. Each case may have a typical tuning/matching, so that only a limited number of points need to be switched through. If outer limits for the detuning of the antenna elements can be found, the range of adaptive tuning/matching that needs to be covered by the antenna device can be estimated.

One implementation is to define a number of antenna configuration states that cover the tuning/impedance matching range. There can be equal or unequal impedance difference between each different antenna configuration state.

<u>Radiation pattern</u>

The radiation pattern of a wireless terminal is affected by the presence of a user or other object in its near-field area. Loss-introducing material will not only alter the radiation pattern, but also introduce loss in radiated power due to absorption.

This problem can be reduced if the radiation pattern of the terminal is adaptively controlled. The radiation pattern (near-field) can be directed mainly away from the loss-introducing object, which will reduce the overall losses.

A change in radiation pattern requires the currents producing the electromagnetic radiation to be altered. Generally, for a small device (e.g. a hand-portable telephone), there need to be quite large changes in the antenna structure to produce altered currents, especially for the lower frequency bands. However, this can be done by switching to another antenna type producing different radiation pattern, or to another antenna structure at another position/side of the PCB of the radio communication device.

Another way may be to switch from an antenna structure that interacts heavily with the PCB of the radio communication device (e.g. whip or patch antenna) to another antenna not doing so (e.g. loop antenna). This will change the radiating currents dramatically since interaction with the PCB introduces large currents on the PCB (the PCB is used as main radiating structure).

An object in the near-field area of a device will alter the antenna input impedance. Therefore, VSWR may be a good indicator of when there are small losses. Small changes in VSWR as compared to VSWR of free space implies small losses due to nearby objects.

The discussion above concerns the antenna near-field and loss from objects in the near-field. However, in a general case, one could be able to direct a main beam in the far-field pattern in a favorable direction producing good signal conditions.

Algorithms (Figs. 4-6)

The received measured operation parameters are processed in some kind of algorithm, which controls the state of the switches. All described algorithms will be of trial-and-error type, since there is no knowledge about the new state util it has been reached.

Below, with reference to Figs. 4-6, some examples of algorithms for controlling the antenna are depicted. A combination of the first and second measured operation parameters, preferably a combination of VSWR and any of BER, (C/N) (C/I) and RSSI, may be used as input, or alternatively, two algorithms are run in parallel and only one parameter is used in each algorithm. For simplicity the VSWR parameter will be used in the discussion below and in Figs. 4-6. It shall, however be clear that it may be replaced by any other suitable parameter, or combination of parameters. In the latter case the term "measure" in Figs. 4-6 should be read as "measure parameters and derive combination parameter".

The simplest algorithm is probably a switch-and-stay algorithm as shown in the flow diagram of Fig. 4. Here switching is performed between predefined states i = 1, …, N (e.g. N = 2, one state being optimized for FS and the other state being optimized for TP). A state i = 1 is initially chosen, whereafter, in a step 65, the VSWR is measured. The measured VSWR is then, in a step 66, compared with predefined limit (the threshold value). If this threshold is not exceeded the algorithm is returned to step 65 and if it is exceeded there is a switching performed to a new state i = i + 1. If i + 1 exceeds N, switching is performed to state 1. After this step

the algorithm is returned to step 65. There may be a time delay to prevent switching on a too fast time scale.

Using such an algorithm, each state 1,… , N is used until the measured operation parameter values exceeds the predefined limit. When this occurs the algorithm steps through the predefined states until a state is reached, which has an operation parameter value below threshold. Both the transmitter and receiver antenna structures can be switched at the same time. An arbitrary number of states may be defined, enabling switching to be performed between a manifold of states.

Another example is a more advanced switch-and-stay algorithm as shown in the flow diagram of Fig. 5. In the same way as previous algorithm, N states are predefined, and a state i = 1 is initially chosen, whereafter, in a step 68, the VSWR is measured, and, in a step 69, compared with the threshold value. If the threshold is not exceeded the algorithm is returned to step 68, but if it is exceeded, a step 69 follows, wherein all states are switched through and VSWR is measured for each state. All VSWR's are compared and the state with lowest VSWR is chosen.

Step 70 may look like:

```
for i = 1:N
    switch to State i
    measure VSWR(i)
    store VSWR(i)
switch to State of lowest VSWR
```

Finally the algorithm is returned to step 68. Note that this algorithm may require quite fast switching and measuring of the operation parameter, since all states have to be switched

through in step 70. Hence, VSWR may be a better choice than BER for this algorithm.

A further alternative algorithm particularly suited for an antenna structure having a manifold of predefined antenna configuration states, which may be arranged so that two adjacent states have radiating properties that deviates only slightly. In Fig. 6 is shown a flow diagram of such a further algorithm.

N states are predefined, and initially a state i = 1 is chosen, a parameter VSWRold is set to zero, and a variable "change" is set to +1. In a first step 71 VSWRi (VSWR of state i) is measured and stored, whereafter in a step 72 the VSWRi is compared with VSWRold. If, on one hand, VSWRi < VSWRold a step 73 follows, wherein a variable "change" is set to +change (this step is not really necessary). Steps 74 and 75 follow, wherein VSWRold is set to present VSWR, i.e. VSWRi, and the antenna configuration state is changed to i + "change", i.e. i = i + change, respectively. The algorithm is then returned to step 71. If, on the other hand, VSWRi > VSWRold, a step 76 follows, wherein variable "change" is set to -change. Next, the algorithm continues to step 74 and 75. Note that in this case the algorithm changes "direction".

It is important to use a time delay to run the loops (71, 72, 73, 74, 75, 71 and 71, 72, 76, 74, 75, 71, respectively) only at specific time steps, as the switched state is changed at every loop turn. At 72 a present state (VSWRi) is compared with the previous one (VSWRold). If the VSWR is better than the previous state, a further change of state in the same "direction" is performed. When an optimum is reached the antenna configuration state as used will typically oscillate,

between two adjacent states at every time step. When end states 1 and N, repectively, are reached, the algorithm may not continue further to switch to states N and 1, respectively, but stays preferably at the end states until it switches to states 2 and N-1, respectively.

The algorithm assumes relatively small differences between two adjacent states, and that the antenna configuration states are arranged so that the rate of changes between each state is roughly equal. This means that between each state there is a similar quantity of change in, for example, resonance frequency. For example, small changes in the separation between feed and ground connections at a PIFA antenna structure would suit this algorithm perfectly, see Fig. 3.

In all described algorithms it may be necessary to perform the switching only in specific time intervals adapted to the operation of the radio communication device.

As a further alternative (not shown in the Figures), control device 22 of Fig. 1 may hold a look-up table with absolute or relative voltage standing wave ratio (VSWR) ranges, of which each is associated with a respective antenna configuration state. Such a provision would enable control device 20 to refer to the look-up table for finding an appropriate antenna configuration state given a measured VSWR value, and for adjusting switching device 14 to the appropriate antenna configuration state.

<u>Further antenna configurations (Figs. 7a-f)</u>

Next, with reference to Figs. 7a-f, various examples of arrangements of antenna structures and switching devices for selectively connecting and disconnecting the antenna structure

as part of antenna module 1 according to the present invention, will briefly be described.

Consider first Fig. 7a, which shows an antenna structure pattern arranged around a switching device or unit 81. The antenna structure comprises receiving antenna elements, here in the form of four loop-shaped antenna elements 82. Within each of the loop-shaped antenna elements 82 a loop-shaped parasitic antenna element 83 is formed.

Switching unit 81 comprises a matrix of electrically controllable switches (not shown) arranged for connecting and disconnecting antenna elements 82 and 83. The switches may be PIN diode switches, or GaAs field effect transistors, FET, but are preferably microelectromechanical system (MEMS) switches.

By means of the switching unit 35 the loop-shaped antenna elements can be connected in parallel or in series with each other, or some elements can be connected in series and some in parallel. Further, one or more elements can be completely disconnected or connected to ground (not shown).

Next, considering Fig. 7b, which shows an alternative antenna structure. It comprises all the antenna elements of Fig. 7a and further, between each pair of loop-shaped elements 82, 83, a meander-shaped antenna element 84. One or more of the meander-shaped antenna elements 84 can be used separately or in any combination with the loop antenna elements.

In Fig. 7c-e are shown antenna structures comprising two slot antenna elements 85, two meander-shaped antenna elements 87, and two patch antennas 89, repectively, connected to switching device 81. Each antenna element 85, 87, 89 may be fed at alternative spaced feed connections 86, 88, 90.

Finally, Fig. 7f shows an antenna structure comprising a whip antenna 91 and a meander-shaped antenna element 92 connected to switching device 81.

The antenna device described above is part of an antenna concept, which is further elaborated and detailed in our co-pending Swedish patent applications entitled "An antenna device for transmitting and/or receiving RF waves", "Antenna device and method for transmitting and receiving radio waves", and "Antenna device for transmitting and/or receiving radio frequency waves and method related thereto", all of which were filed the same very date as the present application, which applications hereby are incorporated by reference.

It will be obvious that the invention may be varied in a plurality of ways. Such variations are not to be regarded as a departure from the scope of the invention. All such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the appended claims.

CLAIMS

1. An antenna device (1) for transmitting and receiving radio frequency waves, installable in a radio communication device, and comprising;

- an antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) switchable between a plurality of antenna configuration states, each of which is distinguished by a set of radiation parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern, and

- a switching device (11, 14, 36, 81) for selectively switching said antenna structure between said plurality of antenna configuration states, characterized by

- a first receiving means for receiving a first measured operation parameter indicative of the quality of transmission of radio frequency waves by said antenna structure,

- a second receiving means for receiving a second measured operation parameter indicative of the quality of reception of radio frequency waves by said antenna structure, and

- a control device (22) for controlling said switching device, and thus the selective switching of said antenna structure between said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, so as to improve the quality of said transmission and/or said reception.

2. The antenna device as claimed in Claim 1, characterized in that said control device (22), at

installation of said antenna device in a particular model of radio communication device, is arranged for controlling said switching device (11, 14, 36, 81) to switch between said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, so as to adapt said antenna device to suit said model.

3. The antenna device as claimed in Claim 1 or 2, characterized in that said receiving means are arranged for receiving the first and second measured operation parameters repeatedly.

4. The antenna device as claimed in Claim 3, characterized in that said control device (22), during use of said antenna device in a radio communication device, is arranged for controlling said switching device (11, 14, 36, 81) to switch between said plurality of antenna configuration states, in dependence on said repeatedly received first and second measured operation parameters, so as to dynamically adapt said antenna device to any object in the close-by environment of said radio communication device.

5. The antenna device as claimed in any of Claims 1-4, characterized in that each of said plurality of antenna configuration states is adapted for use of the antenna device (1) in said radio communication device in a respective predefined operation environment.

6. The antenna device as claimed in Claim 5, characterized in that a first antenna configuration state of said plurality of antenna configuration states is adapted for use of the antenna device in said radio communication device in free space and a second antenna

configuration state of said plurality of antenna configuration states is adapted for use of the antenna device in said radio communication device in talk position.

7. The antenna device as claimed in Claim 6, characterized in that a third antenna configuration state of said plurality of antenna configuration states is adapted for use of the antenna device in a radio communication device in waist position.

8. The antenna device as claimed in Claim 7, characterized in that a fourth antenna configuration state of said plurality of antenna configuration states is adapted for use of the antenna device in a radio communication device in pocket position.

9. The antenna device as claimed in any of Claims 1-8, characterized in that it is arranged for switching frequency band in dependence on said received first and second measured operation parameters.

10. The antenna device as claimed in any of Claims 1-9, characterized in that it is arranged for connection or disconnection of diversity functionality, in dependence on said received first and second measured operation parameters.

11. The antenna device as claimed in any of Claims 1-10, characterized in that said control device (22) is arranged for controlling the switching device (11, 14, 36, 81) to selectively switch (67, 70, 75) the antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) between said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, or a

combination thereof, exceeding (66, 69, 72) or falling below a respective threshold value.

12. The antenna device as claimed in any of Claims 1-10, characterized in that

- said control device (22), in dependence on said received first and second measured operation parameters, or a combination thereof, exceeding (66, 69, 72) or falling below a respective threshold value, is arranged for controlling the switching device (11, 14, 36, 81) to selectively switch (70) the antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) through said plurality of antenna configuration states,

- said receiving means is arranged for receiving a respective first and second measured operation parameter for each antenna configuration state, and

- said control device (22) is further arranged for controlling the switching device to selectively switch (70) the antenna structure to the antenna configuration state with the most advantageous set of operation parameters.

13. The antenna device as claimed in any of Claims 1-10, characterized in that said control device (22) is arranged for comparing (72) said received first and second measured operation parameters, or a combination thereof, with previously received first and second measured operation parameters, or a combination thereof, and for switching (75) the antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) in dependence on said comparison.

14. The antenna device as claimed in any of Claims 1-10, characterized in that said control device (22) holds a

look-up table with combinations of received first and second measured operation parameter ranges, of which combinations each is associated with a respective antenna configuration state, and that said control device is arranged to refer to said look-up table for adjusting said switching device (11, 14, 36, 81) to the respective antenna configuration state.

15. The antenna device as claimed in any of Claims 1-14, characterized in that the plurality of antenna configuration states comprise different numbers of connected antenna elements (12, 13, 50-54, 82-85, 87, 89, 91, 92).

16. The antenna device as claimed in any of Claims 1-15, characterized in that the plurality of antenna configuration states comprise differently arranged feed connections.

17. The antenna device as claimed in any of Claims 1-14, characterized in that the plurality of antenna configuration states comprise differently arranged ground connections (64).

18. The antenna device as claimed in any of Claims 1-17, characterized in that said first measured operation parameter is a measure representing the reflection coefficient, such as a voltage standing wave ratio (VSWR), and that said second measured operation parameter is a measure representing bit error rate (BER), carrier-to-noise (C/N) ratio, carrier-to-interference (C/I) ratio, or received signal strength.

19. The antenna device as claimed in Claims 18, characterized in that it comprises a device (10) for measuring the reflection coefficient, particularly the voltage

standing wave ratio, and for sending the reflection coefficient value to the first receiving means.

20. The antenna device as claimed in Claims 18 or 19, characterized in that it comprises a device for measuring the received signal strength and for sending the signal strength value to the second receiving means.

21. The antenna device as claimed in any of Claims 1-20, characterized in that said first and second receiving means are provided as a single receiving element.

22. The antenna device as claimed in any of Claims 1-21, characterized in that said control device (22) comprises a central processing unit (23) and a memory (24) for storing antenna configuration data.

23. The antenna device as claimed in any of Claims 1-22, characterized in that said switching device (11, 14, 36, 81) comprises a microelectromechanical system (MEMS) switch device.

24. The antenna device as claimed in any of Claims 1-23, characterized in that said antenna structure comprises a switchable antenna element having any of meander (84, 87, 92), loop (82), slot (85), patch (89), whip (91), helical, spiral, and fractal configurations.

25. The antenna device as claimed in any of Claims 1-24, characterized in that

- the antenna structure (12, 13) comprises a transmitting antenna structure (12) and a receiving antenna structure (13) and

- said switching device (11, 14) comprises a transmitter switching device (11) a receiver switching device (14),

- said transmitting antenna structure (12) and said transmitter switching device (11) being arranged in a transmitter antenna device (9), whereas said receiving antenna structure (13) and said receiver switching device (14) being arranged in a receiver antenna device (15), wherein

- said transmitter antenna device (9) and said receiver antenna device (15) are controllable independently of each other by said control device (22).

26. A radio communication device, characterized in that it comprises an antenna device according to any of Claims 1-25.

27. In an antenna device (1) installable in a radio communication device, and comprising

- an antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) switchable between a plurality of antenna configuration states, each of which is distinguished by a set of radiation parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern, and

- a switching device (11, 14, 36, 81) for selectively switching said antenna structure between said plurality of antenna configuration states, a method for transmitting or receiving radio frequency waves, characterized by the steps of:

- receiving a first measured operation parameter indicative of the quality of transmission of radio frequency waves by said antenna structure,

- receiving a second measured operation parameter indicative of the quality of reception of radio frequency waves by said antenna structure, and

- controlling said switching device, and thus the selective switching of said antenna structure between said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, so as to improve the quality of said transmission and/or said reception.

28. The method as claimed in Claim 27, characterized by controlling said switching device (11, 14, 36, 81) to switch between said plurality of antenna configuration states, at installation of said antenna device in a particular model of radio communication device, in dependence on said received first and second measured operation parameters, so as to adapt said antenna device to suit said model.

29. The method as claimed in Claim 27 or 28, characterized by receiving the first and second measured operation parameters repeatedly.

30. The method as claimed in Claim 29, characterized by controlling said switching device (11, 14, 36, 81) to switch between said plurality of antenna configuration states, during use of said antenna device in a radio communication device, in dependence on said repeatedly received first and second measured operation parameters, so as to dynamically adapt said antenna device to objects in the close-by environment of said radio communication device.

31. The method as claimed in any of Claims 27-30, wherein each of said plurality of antenna configuration states is adapted

for use of the antenna device (1) in said radio communication device in a respective predefined operation environment.

32. The method as claimed in any of Claims 27-31, characterized by switching frequency band in dependence on said received first and second measured operation parameters.

33. The method as claimed in any of Claims 27-32, characterized by connecting or disconnecting diversity functionality, in dependence on said received first and second measured operation parameters.

34. The method as claimed in any of Claims 27-33, characterized by controlling the switching device (11, 14, 36, 81) to selectively switch (67, 70, 75) the antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) between said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, or a combination thereof, exceeding (66, 69, 72) or falling below a respective threshold value.

35. The method as claimed in any of Claims 27-33, characterized by the steps of:

- controlling the switching device (11, 14, 36, 81) to selectively switch (70) the antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) through said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, or a combination thereof, exceeding (66, 69, 72) or falling below a respective threshold value,

- receiving a respective first and second measured operation parameter for each antenna configuration state, and

- controlling the switching device to selectively switch (70) the antenna structure to the antenna configuration state with the most advantageous set of operation parameters.

36. The method as claimed in any of Claims 27-33, characterized by comparing (72) said received first and second measured operation parameters, or a combination thereof, with previously received first and second measured operation parameters, or a combination thereof, and switching (75) the antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) in dependence on said comparison.

37. The method as claimed in any of Claims 27-33, characterized by storing a look-up table with combinations of received first and second measured operation parameter ranges, of which combinations each is associated with a respective antenna configuration state, and referring to said look-up table for adjusting said switching device (11, 14, 36, 81) to the respective antenna configuration state.

ABSTRACT

The present invention comprises an antenna device (1) for transmitting and receiving radio frequency waves, installable in a radio communication device, and comprising an antenna structure (12, 13, 35, 61, 82-85, 87, 89, 91, 92) switchable between a plurality of antenna configuration states, each of which is distinguished by a set of radiation parameters, such as resonance frequency, input impedance, bandwidth, radiation pattern, gain, polarization, and near-field pattern, and a switching device (11, 14, 36, 81) for selectively switching said antenna structure between said plurality of antenna configuration states. The device comprises further a first receiving means for receiving a first measured operation parameter indicative of the quality of transmission of radio frequency waves by said antenna structure, a second receiving means for receiving a second measured operation parameter indicative of the quality of reception of radio frequency waves by said antenna structure, and a control device (22) for controlling said switching device, and thus the selective switching of said antenna structure between said plurality of antenna configuration states, in dependence on said received first and second measured operation parameters, so as to improve the quality of said transmission and/or said reception.

(Fig. 1 suggested for publication)

PRV 99-10-29

1/5

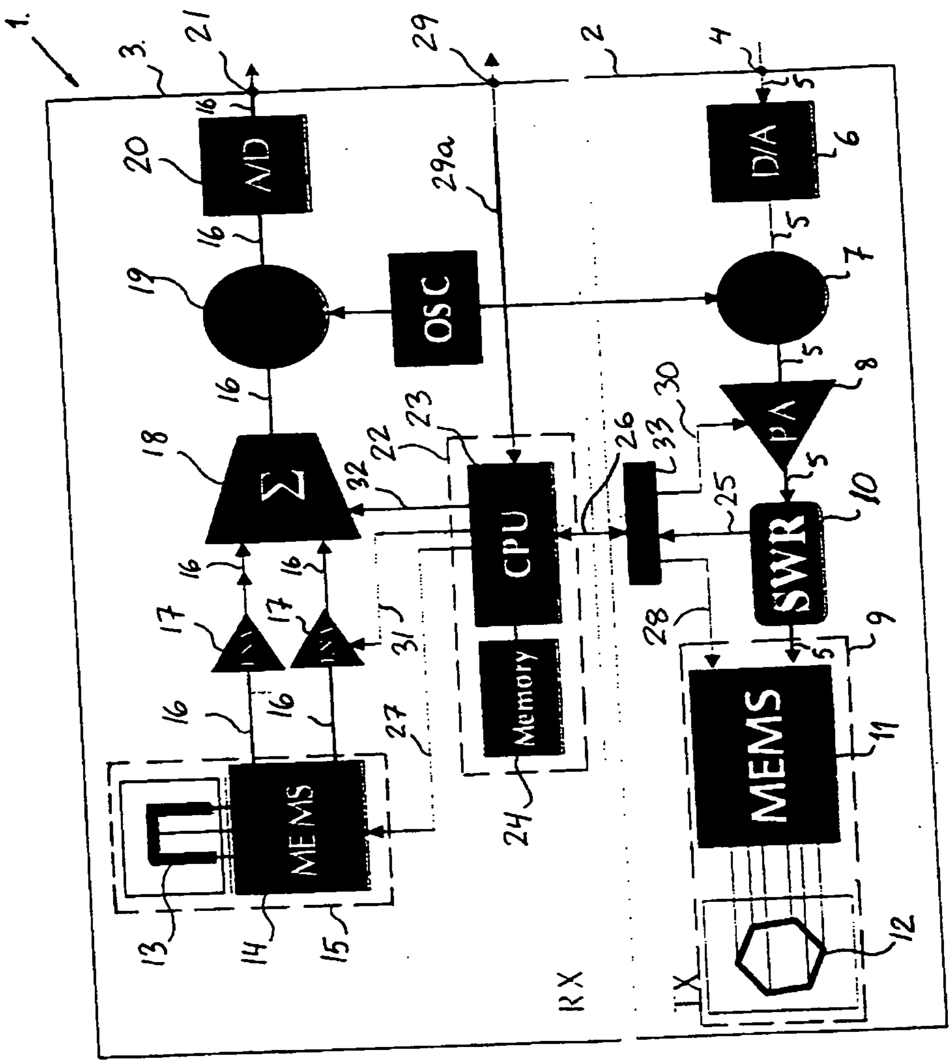

Fig. 1

9903944-0

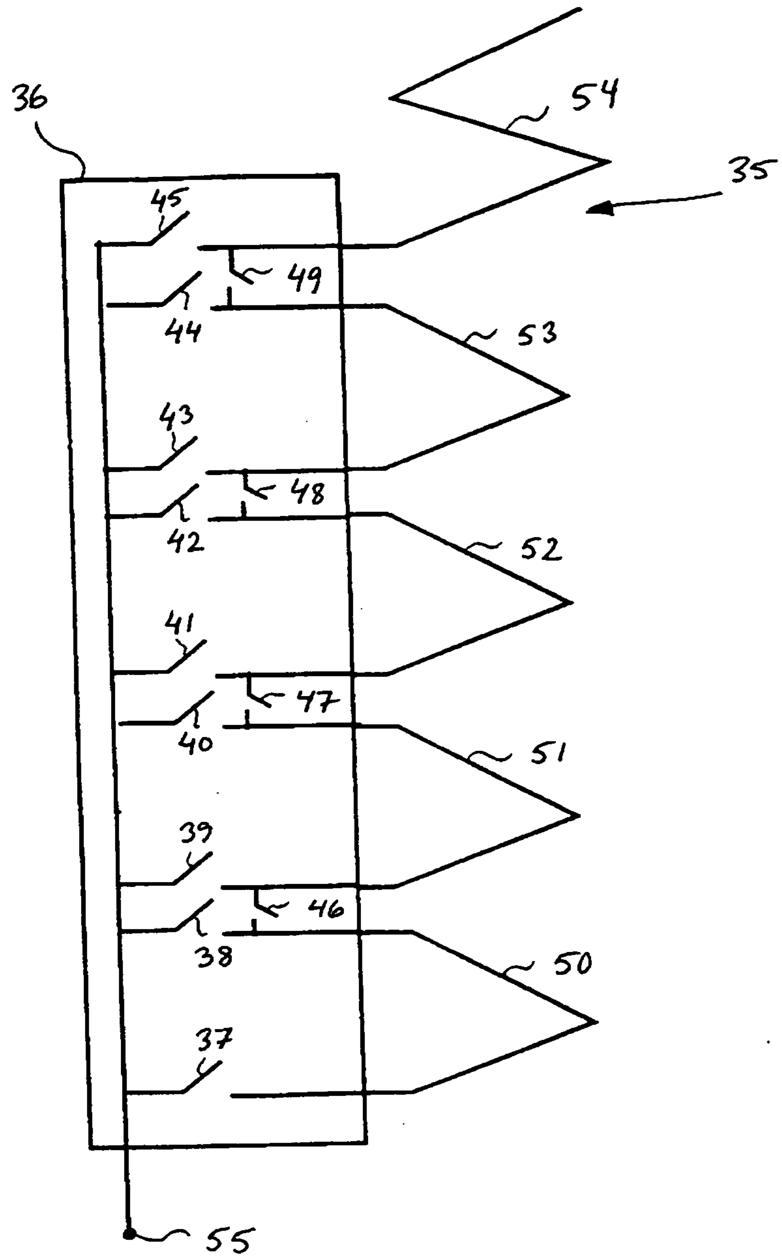

Fig. 2

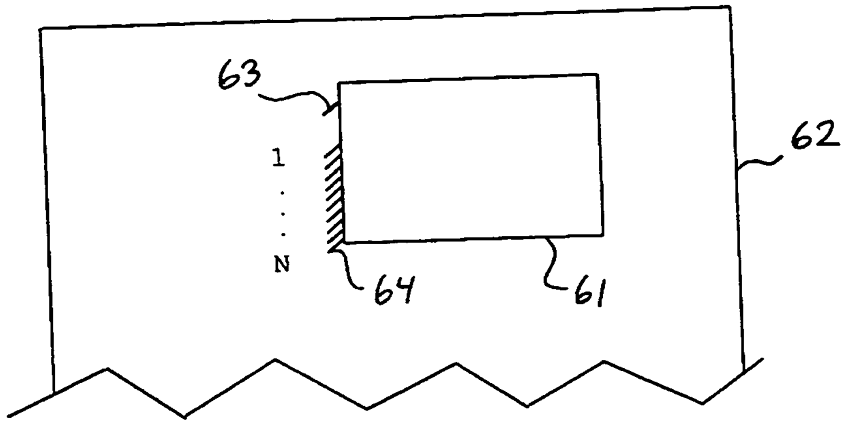
63
1
N
62
64
61

Fig. 3

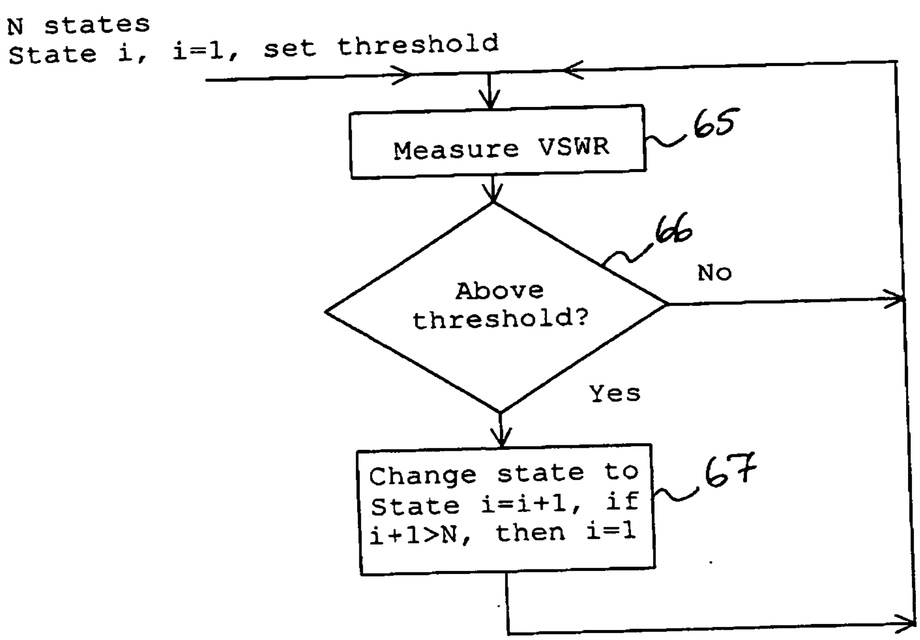
N states
State i, i=1, set threshold
Measure VSWR
65
66
Above threshold?
No
Yes
Change state to State i=i+1, if i+1>N, then i=1
67

Fig. 4

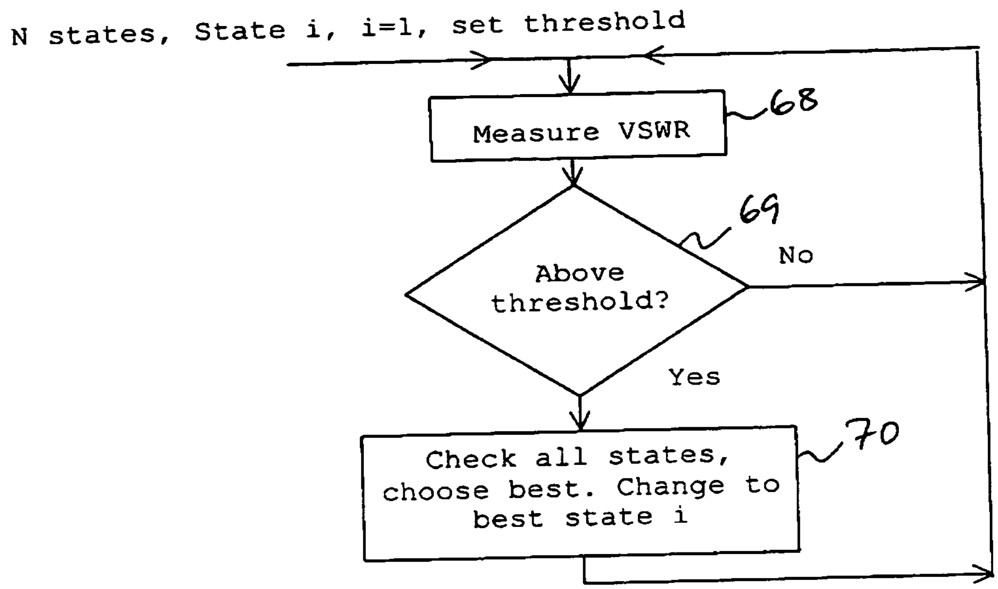
N states, State i, i=1, set threshold
Measure VSWR
68
Above threshold?
69
No
Yes
Check all states, choose best. Change to best state i
70

Fig. 5

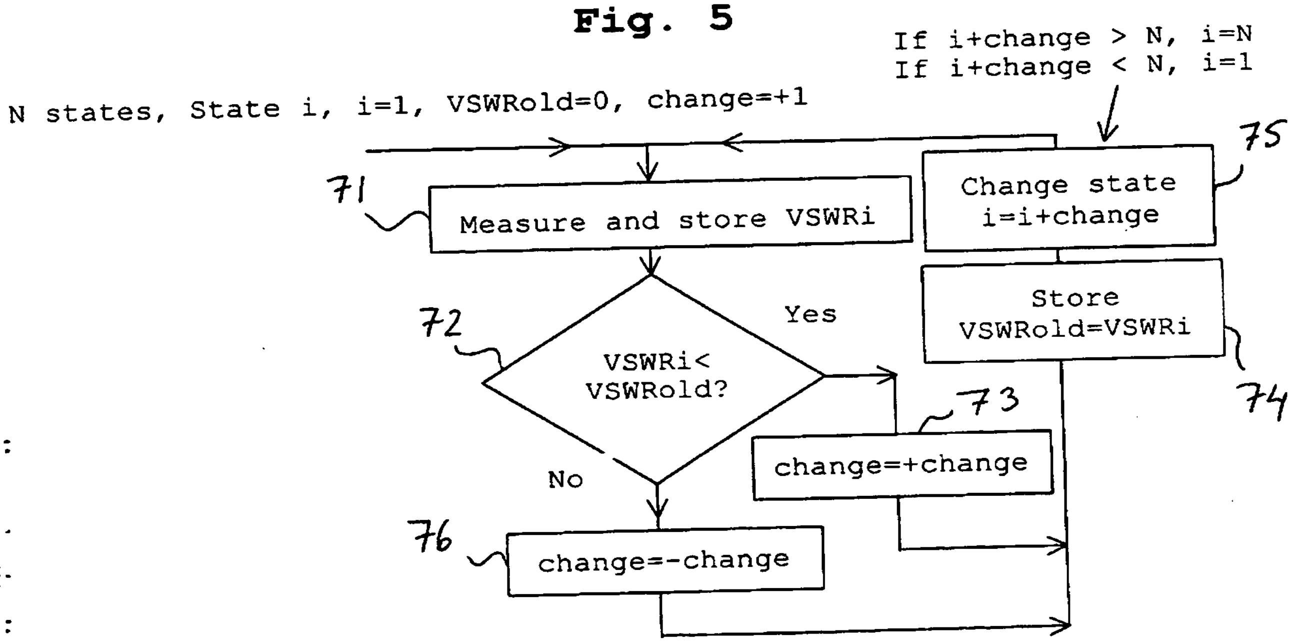
If i+change > N, i=N
If i+change < N, i=1
N states, State i, i=1, VSWRold=0, change=+1
Measure and store VSWRi
71
Change state i=i+change
75
Store VSWRold=VSWRi
74
VSWRi< VSWRold?
72
Yes
No
change=+change
73
change=-change
76

Fig. 6

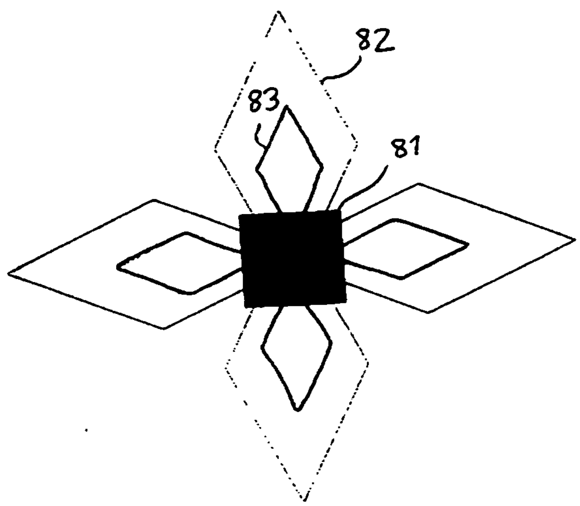

Fig. 7a

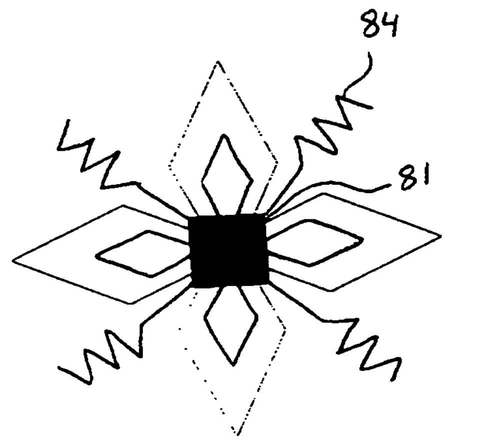

Fig 7b.

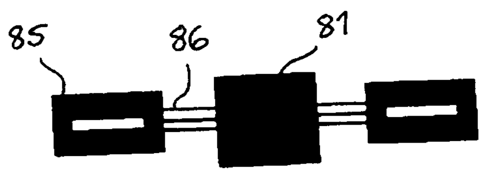

Fig. 7c

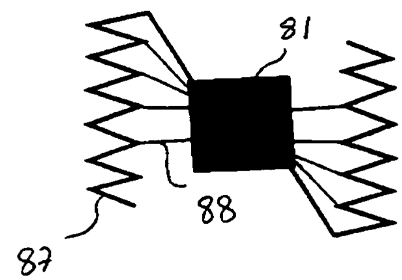

Fig. 7d

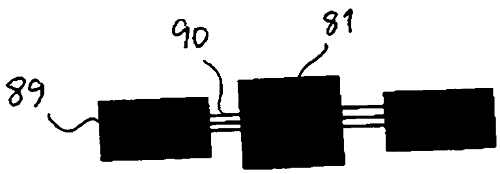

Fig. 7e

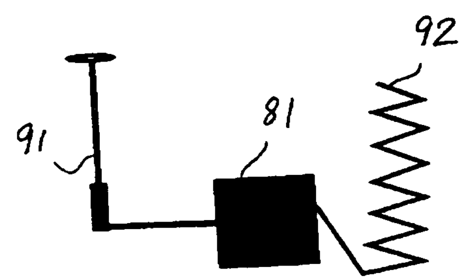

Fig. 7f